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APPLICATION OF ELECTRONIC COMPUTER TECHNIQUES TO RACIAL INTEGRATION IN SCHOOL SYSTEMS.

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THIS REPORT DESCRIBES A COMBINED COMPUTER SYSTEM (MINITRAN-MPS/360) WHICH HAS BEEN DESIGNED TO DETERMINE THE FEASIBILITY OF MASS-TRANSPORTATION TO ACHIEVE A SPECIFIED ETHNIC DISTRIBUTION IN EACH SCHOOL IN A GIVEN COMMUNITY. IN ADDITION TO A NARRATIVE DISCUSSION OF VARIOUS OPERATIONAL PROCEDURES AND CONCEPTS, THE REPORT INCLUDES MINITRAN FLOW DIAGRAMS, SAMPLE INPUT CARDS FOR A HYPOTHETICAL COMMUNITY ("DUCKBURG"), A "DUCKBURG" COMMUNITY MAP, AND "DUCKBURG" CENSUS DATA. IT ALSO CONTAINS MINITRAN-MPS/360 OUTPUT FOR "DUCKBRUG" AND INSTRUCTIONS FOR RUNNING THESE COMPUTER PROGRAMS. (LB)

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November 1967

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FINAL REPORT

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Application of Electronic Computer Techniques to Racial Integration in School Systems

Project No. 0113-26522
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Stevens H. Clarke (Project Director)
Julius Surkis (Co-Investigator)
30 November 1967

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I. INTRODUCTION

Since the landmark Supreme Court decision in 1954 invalidating school segregation, the problem of racial desegregation of school systems has received a great deal of attention. In urban communities, where residential patterns produce de facto segregation of schools, many school administrations have adopted an official policy of eliminating such segregation. Clearly, this is not a simple matter. There are significant legal and political obstacles; for example, it is by no means clear that the 1954 Brown ruling extends to de facto (i.e. "unintentional") segregation. In addition, complex logistical difficulties are involved. In view of the latter, one might well conclude that the goal of desegregation can be achieved only when educational facilities are clustered in centralized educational parks. The educational park system, although under consideration by many school systems, cannot be expected to be prevalent for some time.

The interest of the authors was to find some irreducible "kernel" of the urban school desegregation problem which could be dealt with mathematically. It was felt that it would be an advantage to school planners to know that, whatever programs were undertaken to achieve desegregation, the total effort would be at least as difficult as solving this kernel problem. In formulating the problem, the authors were guided by the following considerations. First, desegregation must involve some numerically specified ethnic composition requirement for each school plant in the system. Second, only existing school plants

should be considered. The construction of new facilities, be they conventional school buildings or educational parks, require major decisions regarding site choice, bond issues, and the like, which, in the authors' judgment, should not be included in the kernel problem. Third, the school administration must have the power to assign students to schools on the basis of race when the purpose is to correct racial imbalance. The constitutionality of such power is open to doubt. The U. S. Supreme Court has thus far not spoken on the issue despite the many opportunities for it to do so. However, given the hard fact of residential segregation, it is obvious that elimination of school segregation requires that a school administration consciously act on the basis of the ethnicity of each of its students.

With the above considerations in mind, the problem chosen was that of using available mass transportation most effectively to achieve a given ethnic mix in each school in a community. The objection can be raised that this choice ignores the plight of some urban areas which lack adequate mass transportation systems. The techniques developed to deal with the kernel problem meet this objection to some extent (see Section II (F) below). Discussion with school officials has confirmed that the study of transportation feasibility is an element of any serious effort at overcoming residential segregation.

Having settled on the transportation aspect of the desegregation problem, the objective of the authors was to develop and test a computerized system which would solve, or help to solve, the problem.

The combined MINTRAN-MPS/360 system, described in detail in the following sections of this report, is submitted as a planning tool for school administrators. Card decks of tested, running computer programs, as well as flow diagrams and input format descriptions, are being provided to the Office of Education to make the system generally available.

II. STATEMENT OF PROBLEM

The problem is generally defined in subsection (A), mathematically stated in (B), and is explicated in the remaining subsections.

A. General Definition of Urban School Desegregation Problem.

GIVEN: (G.1) The residential distribution of students in a community, by race and grade, over small areas - Census Tracts, city blocks, etc.;

(G.2) The location and capacity of existing school buildings;

(G.3) A specified ethnic composition for each school (which may vary among schools), expressed as percentage ranges;

(G.4) The configuration of mass transportation lines in the community (or, alternately, of principal streets), with average speeds for each type of transportation;

(G.5) The maximum allowable daily transportation* time and walking distance per student;

FIND: A table of assignmnet of students to school buildings which

(F.1) Places each student in a school;

(F.2) Satisfies the given transportation time and walking distance constraints;

(F.3) Achieves an ethnic composition within the given percentage ranges for each school;

(F.4) Minimizes the total daily student transportation time subject to F.1, F.2, and F.3.

Of course there may be no feasible solution to the above problem. It

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*"Transportation" does not include walking.

should be emphasized that the problem statement does not require contiguous school attendance districts, which are the conventional means of assigning students to schools. Also note that student transportation time is the objective function to be minimized, rather than transportation cost. Time was chosen because (a) student-mile costs are very difficult to estimate; (b) an assignment arrangement which minimizes transportation time probably brings real cost close to its minimum; and (c) student time is as good a single measure as any of the inconvenience of transportation.

B. Mathematical formulation.

Subsection (A) defines a multi-commodity distribution problem, where the areas of student residence (hereafter called "tracts") are sources, the schools are destination points, and each ethnic group is a commodity. The costs are the times, over minimal-time transportation routes, from each tract i to each school j. The maximum transportation time constraint of (G.5) is included as follows. If for the pair (i,j), there is no route which does not exceed the maximum time T, any activity for (i,j) will be eliminated by setting it to zero. However, for any tract i, there must be some school j accessible by a route not exceeding T. This is assumed in the following equations, and the MINTRAN system verifies the assumption for each input tract. The maximum walking distance constraint is handled implicitly; see subsection (H) below.

The problem may be now formulated as follows.

Let X_{ijk} = the activity level of the k th ethnic group assigned from the i th tract to the j th school.
NOTE: If for any (tract, school) pair (i,j) there is no route connecting i to j which does not exceed the maximum time T, then for all k, $X_{ijk} = 0$.

C_j = the total capacity of the j th school.

U_{jk} = the maximum number of students of the k th ethnic group at the j th school.

L_{jk} = the minimum number of students of the k th ethnic group at the j th school.

S_{ik} = the available number of students of the k th ethnic group at the i th tract.

t_{ij} = the daily one-way transportation time, in minutes, over a minimal route from the i th tract to the j th school.

K = total number of ethnic groups

m = total number of tracts

n = total number of schools

To satisfy the ethnic requirements at each school j:

$$\left.\begin{array}{lllll} L_{j1} \leq X_{1j1} + X_{2j1} + \cdots + X_{mj1} \leq U_{j1} \\ L_{j2} \leq X_{1j2} + X_{2j2} + \cdots + X_{mj2} \leq U_{j2} \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ L_{jK} \leq X_{1jK} + X_{2jK} + \cdots + X_{mjK} \leq U_{jK} \end{array}\right\} \text{for K ethnic groups}$$

The school capacity of each school j must not be exceeded, so

for any j: $\sum_k \sum_i X_{ijk} \leq C_j$

For the availability at each tract i of students in each of K ethnic groups: $X_{i11} + X_{i21} + \ldots + X_{inl} = S_{il}$

$$X_{i12} + X_{i22} + \ldots + X_{in2} = S_{i2}$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$X_{i1K} + X_{i2K} + \ldots + X_{inK} = S_{iK}$$

The objective function to be minimized is $Z = \sum_k \sum_j \sum_i t_{ij} X_{ijk}$

It is assumed that $\sum_i \sum_k S_{ik} \leq \sum_j C_j$, i.e., that the total school capacity is at least as great as the total number of students. If this relation does not hold in an actual case, the MINTRAN system, at the user's option, will simply prorate the required extra capacity over all the school capacities, so that each C_j will reflect an upward adjustment.

Note that the L_{jk} and the U_{jk}, i.e., the lower and upper bounds on each ethnic group at each school, are absolute figures, which the MINTRAN package computes from the school capacities and the percentage ranges furnished by the user (see G.4 above). This means that if the total school capacity significantly exceeds the total of students, confusion results if the user does not reduce the various school capacities to remove the excess.

Being a typical multi-commodity distribution problem, the above urban school desegregation problem can be solved by most linear programming codes, once the "costs", i.e. the minimal transportation

times t_{ij}, are known. The MINTRAN package computes the t_{ij} (see Section IV below) and is designed to be used in conjunction with MPS/360, the general-purpose mathematical programming system of International Business Machines Corporation.

C. Treatment of Student Ethnic Distribution.

At present, the MINTRAN package permits up to three ethnic groups; slight modifications would be required to allow more than three. The distribution of the ethnic groups is described by a set of data for each small area in the user's community - Census Tract, block, block face, etc. Each data set consists of tallies, for each grade and race, of students residing in the area

Tabulations by characteristics other than race could also be included, of course. If the objective is to integrate students according to educational need (vocational, commercial, college preparatory) as well as race, then a set of pairs will characterize each group to be integrated; e.g., (Race A, vocational), (Race B, commercial), etc. In general, for assignment of individuals with different needs to public service facilities with various mixes of service capacities, the distribution of each need category can be handled as an ethnic group is handled.

D. Location and Capacity of Schools.

The location of a school building is simply its integral coordinates on a grid superimposed over a map of the community. This same grid, of course, must be used for tract locations and

transportation line or street configurations. The unit of the grid, at the scale of the map, should be less than the maximum walking distance, preferrably about one-fourth of it. The reason for this (see Subsection (H) below) is that all locations are expressed as pairs of integers, and the round-off error for any location should not interfere with the walking distance limitation.

For the capacity of each school, the school administration will typically have an official figure based on a ratio of classrooms and equipment to students. What about the grade organization of each school? The problem defined by II(A) and II(B) above can be considered a single-grade problem, in which case the school capacity figures for each school would be for one grade only, as would the student ethnic distribution figures. The grade-at-a-time approach requires a MINTRAN-MPS/360 run for each grade. It is also possible to deal with several grades at once, aggregating the students in the grades and the various grade capacities. The latter approach, since it ignores the individual grades, may result in filling entirely with third-grade students a school normally serving grades one through six, or filling it entirely with first and fourth-grade students, etc. This may or may not be undesirable from an educational point of view.

E. Ethnic Composition Requirements at Each School.

For each ethnic group at each school, percentage ranges must be specified; this, of course, is a policy decision for school administrators. The chosen set of percentage ranges should be realistic-

ally based on community-wide percentages. Since the ranges may vary among schools, it may be advisable to relax the requirements a bit for schools whose desegregation will clearly be difficult.

F. Configuration of Mass Transportation Lines (or Principal Streets).

In the MINTRAN system, mass transportation lines are treated as points connected by links, the points being coordinate pairs on a grid (see II(D) above). Each transportation line is assumed to have some fixed average speed throughout its length. There is no consideration of the capacity of any section of a transportation line, which means that the problem of possible overloading of the transportation system (due to increased student use) is ignored.

What about communities where mass transportation is inadequate? In such cases, the problem of supplementing available transportation is raised. MINTRAN does not deal with the general question of constructing optimal bus routes. However, principal streets can be used as a travel network by assigning different travel speeds to various street links. In this case, MINTRAN will compute the minimal-time route from each tract to each school; here the minimal route is the best direct street path rather than the best path over fixed transportation lines. The minimal street travel times can be used as the t_{ij} in the problem defined in II(B), and should result in a "good" assignment of students to schools. The resulting assignment will probably not be optimal, because ultimately a school transportation

system will have to be designed, and such a system will probably not consist of direct paths from each tract to each school. Nevertheless, in designing a school transportation system it is valuable to have the minimal direct street routes. Such routes are a necessary first step in many vehicle routing schemes such as that of Clarke and Wright.*

G. Walking Distance and Transportation Time Constraints.

The user of MINTRAN should set a limit, in minutes, on the time any student spends being transported (one-way) to school. This limit is handled by the minimal routes program; see II(B) above. It is also advisable to specify a walking distance limit (in terms of grid units), whose function is explained in the following subsection.

H. Completion of Travel Network.

The network of mass transportation lines has to be augmented to include all possibilities for walking: from tract to line, from line to line where transfer is permitted, and from line to school. In the input to MINTRAN, a walking distance limit of W grid units means, for example, that a student may walk W units directly to a school, W units to a bus (or other carrier) stop, W units to transfer from one bus to another bus, and W units from a bus stop to a school. Consequently a student may be required to walk 2W units or more. It is suggested that W be about one-half of the allowable one-way walking distance maximum (expressed in grid units). Such a maximum is set by statute in many states.

*G. Clarke and J. W. Wright, "Scheduling of Vehicles from a Central Depot to a Number of Delivery Points," The Journal of the Operations Research Society of America, Vol. 12, Jul.-Aug. 1964, pp. 568-582.

A travel link representing walking from a tract direct to a school, from a tract to a transportation line, or from a line to a school, is assigned a time of zero minutes. A link representing transfer, including walking and waiting, from one line to another, is assigned some fixed time of, say, ten or fifteen minutes.

The accessibility of a transportation line can be handled in one of two ways. If frequent stops are made along the line, it can be considered accessible at any point. Otherwise, it is accessible only at particular points which must be specially designated.

III. ETHNIC DATA SOURCES

Small-area data on students, by race and grade attended, is absolutely necessary to allow flexibility in assignment to schools. The most obvious source is the U. S. Bureau of the Census. The authors did employ Census data in the Brooklyn test run described in Section V, but there are many disadvantages involved. Since Tract or Block level data are needed, published Census figures are inadequate*, and special tallies must be purchased from the Census Bureau. The data is inaccurate because it is decennial and is often based on a partial sample.

Any school administration wishing to eliminate desegregation needs accurate small-area data. The most practical approach would be to collect unit records - street address, grade attended, and race - as part of the yearly enrollment procedure. This data could then be aggregated to block or Tract using a geographic coding guide. Laws in some states prohibit the keeping of records on the ethnicity of individual students. To comply with such laws, it may or may not be sufficient to ensure that only the student's address, and not his name, is recorded in a grade and ethnic group.

*See U. S. Censuses of Population and Housing: 1960, Census Tracts Final Report, PHC(1)-104, Part 1, Tables P-1, P-2, P-4; none of these show grade and race together.

IV. COMPUTER IMPLEMENTATION

To develop the minimal transportation times t_{ij} (see Section II(B) above), a set of eight computer programs, known as "MINTRAN" and written in Fortran IV, is used. MINTRAN incorporates the transportation times in its output, which is a problem description in a format acceptable to MPS/360. After MPS/360 reaches a primal solution (if any) to the problem, an analyzer program (also written in Fortran IV) converts the MPS/360 output to a detailed listing of student assignments, fare costs, travel times, recommended minimal paths, and various statistics. Appendix A contains flow diagrams of the MINTRAN system.

A. JS1 - JS5: Card Input and Completion of Transportation Network.

The first five MINTRAN programs, JS1 to JS5, perform the following steps. First, card data are read in: special parameters, student ethnic distribution, location and capacity of schools, ethnic composition requirements, and configuration of mass transportation lines (or principal streets). Then the complete travel network is generated; see II(H) above. This is done by external and internal sorting and by some geometric calculations. The result is two files which together contain all travel links, each with a time.

B. JS6 - JS7: Minimal Routes and MPS Problem Statement.

The next program, JS6, computes minimal time routes from each tract to each school. Only routes of less than T minutes (T being an input parameter) are generated. A check is made to ensure

that there is at least one such route for each tract. The method used is the well-known R.R.L. Algorithm of the British Road Research Laboratory (see Martin, Minimum Path Algorithms for Transportation Planning, M.I.T. Dept. of Civil Engineering, 1963). Modifications were made by the authors to conserve time and memory space.

Using the minimal times developed by JS6, JS7 produces a problem description in MPS/360 format.

C. Execution of MPS/360.

MPS/360 is used to reach a solution (if any exists) of the problem generated by MINTRAN. For a complete description of MPS/360, see the manual: IBM Publication H20-0291-0, released early in 1966.

D. JS8: Analyzer of MPS/360 Output.

The analyzer program, JS8, combines the student assignments computed by MPS/360 with minimal route data from JS6, to produce final printed output. A sample is shown in Appendix E. For each tract, assignments to one or more schools of students in various racial groups are indicated. (In the sample problem, as in the Brooklyn problem, students are aggregated within a grade range rather than treated grade by grade.) The minimal route is shown in each case as a series of nodes, separated by hyphens, starting with the school ("PS") and ending with the tract. Bus line nodes are designated as "TB", subway nodes as "U" (for stations) or "W" (for other points). The last two figures in each node description are the X and Y grid coordinates.

On page four of the sample output, some total time and fare cost figures are given. In its present form, JS8 employs the New York City Transit Authority fare system to compute fares; slight modifications would be required for communities with different fare structures.

V. ACTUAL APPLICATIONS OF MINTRAN-MPS/360 AND EXAMPLES OF INPUT DATA PREPARATION

This section is intended to illustrate the use of MINTRAN MPS/360 and its results, and to describe the preparation of input data. Instructions for executing the computer programs are given in Appendix F. This information, plus a careful reading of Section II of the report, should give the would-be user a good idea of how MINTRAN can be applied to a particular school system. However, any community will have its own peculiarities, and it would be advisable to consult with the authors before MINTRAN is used.

A. Hypothetical Community ("Duckburg").

1. Population characteristics. Appendix C contains a map of the hypothetical community, which was invented as a source of test data. There are four schools ("PS") and twelve tracts. Tracts* are represented by points which are really the geographic centroids of small areas. Two pairs of tracts have the same name, Tract 3 and Tract 711. What this means is that the original tract covered too large an area, and was subdivided into two smaller pieces with two distinct centroids. Thus in the case of Tract 3, there is a Tract 3 with X = 7 and Y = 23, and another Tract 3 with X = 3 and Y = 15. These two subdivisions will not be confused because their coordinates are distinct.

*NOTE: The term "tract" is used here in a generic sense to refer to any small area the user may employ for ethnic distribution - a block, block face, Census Tract, Census Enumeration District, etc.

Appendix D describes the student populations of the various tracts. All of the students are considered to be in the grades K through 6. Tract 820.0 is "empty" — i.e., has no student population. Among the other tracts there is a very uneven distribution of the three races, A, B, and C. The community-wide percentages of 14.5%, 24.7%, and 60.7% were used as the basis of ethnic composition requirements at the schools. The requirements were the same at every school: 7% to 28% Race A, 12% to 48% Race B, and 30% to 81% Race C.

2. Input data. Before examining the output for "Duckburg", it will be helpful to explain how input data was prepared. Appendix B has a sample of the input, one printed line being one card or card image.

INITIAL PARAMETER CARDS. These are the first two input cards. Everything punched in these cards is ignored, except the following fields. (All punching is right-justified and space-filled within the field.)

(FIRST CARD) Col 32-34 : maximum walking distance, in grid units.

Col 54-60 : the scale conversion factor, or the number of miles per map grid unit, carried to four decimal places; e.g. 0.0568.

Col 75-76, 78-79 : grade range to be dealt with in this run. Grade K is punched as 05, grade 1 as 06, etc., and grade 12 as 17. A grade range of K through 6 would be 05 and 11 in cols 75-76 and 78-79. To handle a single grade, say grade 3, both fields would contain 08.

Col 43-48 : maximum student travel time, in minutes and hundredths of minutes.

(SECOND CARD) Col 12-17 : average bus speed in mph, to two decimal places. On the Duckburg map, bus lines are dotted, and the average speed is 8.00 mph.

Col 30-35 : average subway speed in mph, to two decimal places. On the Duckburg map, subway lines are solid, and the average speed is 30.00 mph.

ETHNIC DISTRIBUTION. The next group of cards should be put on a separate card-image tape file. As Appendix F indicates, this file will be on FORTRAN logical unit 13.

The ethnic distribution cards are divided into groups. There is a 15-card group for each tract, plus 15 cards at the end as an end-of-file marker. (Within each group of 15 cards, most columns are blank and are available for additional future information.) The 15-card groups are in order by tract name, according to this collating sequence: blank < zero < 9 < A < Z. On every card of a group, the tract name, such as 0003, is in cols 72-77. Cols 79-80 have the sequence number of the card within the group, which runs from 1 to 15. The Race A figures are punched into cards 1 and 2, Race B in cards 6 and 7, and Race C into cards 11 and 12. The card design is as follows.

RACE A

Card 1:	cols 25-30	Grade K
	31-36	1
	37-42	2
	43-48	3
	49-54	4
	55-60	5
	61-66	6

Card 2:	cols	1-6	Grade 7
		7-12	8
		13-18	9
		19-24	10
		25-30	11
		31-36	12

RACE B

Card 6:	cols	19-24	Grade K
		25-30	1
		31-36	2
		37-42	3
		43-48	4
		49-54	5
		55-60	6
		61-66	7
Card 7:	cols	1-6	8
		7-12	9
		13-18	10
		19-24	11
		25-30	12

RACE C

Card 11:	col	13-18	Grade K
		19-24	1
		25-30	2
		31-36	3
		37-42	4
		43-48	5
		49-54	6
		55-60	7
		61-66	8
Card 12:	cols	1-6	Grade 9
		7-12	10
		13-18	11
		19-24	12

All other cards, i.e., cards 3 through 5, 8 through 10, and 13 through 15, are blank but must be included. The last group of cards consists of 14 blank cards and a 15th card with ZZZZZZ punched in cols 72-77.

NODE CARDS. The next set of cards describes all nodes in the community. A node represents a school, a point on a bus or subway route, or a tract (actually, a tract centroid). A node descriptor consists of four fields, with a total length of fifteen characters. One field is a name. For a tract, this should be six numeric c digits; e.g. 342689. (In the Duckburg case, there are tract names with blanks or hyphens, but the use of non-numerics is not recommended.) For a school, the name field begins with PS; e.g. PSbb83, where b is a blank. For a bus route, the name begins with TB; e.g. TBbbb3. For a subway route, the name begins with U or W; e.g. Ubbbb3 or Wbbbb3. U designates a passenger stop on subway line 3, whereas W is merely a point on subway line 3, without passenger access. Buses are assumed to make such frequent stops that access at any point is allowed.

The X and Y coordinates are two other fields of a node descriptor, being three characters each. Each descriptor begins with a three-character code:

1bb - Tract or School node
1b1 - Tract subdivision node
2bb - Bus or subway line node
3bb - Last node of a connected "chain" of bus or subway line nodes.

Thus, Tract 342689 at X = 13 and Y = 6 would be 1bb342689b13bb6. School 83 at X = 4 and Y = 9 would be 1bbPSbb83bb4bb9. A bus or subway line node descriptor is similar; it would begin with the code 2bb unless it were the last node descriptor punched for a particular

line; in that case its code would be 3bb. Bus and subway lines are assumed to be bidirectional. Hence, the nodes of a line are punched sequentially from one end of the line to the other.

The node cards are designed as follows. First in order are tract node cards, one descriptor per card in cols 1-15, sorted on the X and Y coordinates (cols 10-15), with sequence b < zero < 9. Next are the school node cards, one descriptor per card in cols 1-15, sorted the same way. Then come the cards for bus and subway route nodes; these can be in cols 1-15, 16-30, 31-45, or 46-60, the sequence going from left to right. There is no sorting of descriptors for buses and subways, but the sequence must describe the sequence of points from one end of the line to the other, ending with a "3bb" descriptor. If cols 1-15, 16-30, 31-45, or 46-60 are blank, the field is simply ignored by the program.

SCHOOL CAPACITY OPTION CARD. The next card is used to select an option concerning what action the program will take if the total of students exceeds the total school capacities. Cols 1-22 contain the words

EXCESSbSTUDENTSbOPTION

where b is a blank. Cols 23-24 will be blank-zero or blank-one. Blank-zero will mean that the school capacities will be proportionately adjusted to handle the excess. (This was done in the Duckburg case; note the capacity adjustments on p. 5 of the sample output, Appendix E.) Blank-one in cols 23-24 will mean the program will stop if an excess of students is detected. What about a surplus of

school capacity? If the user is aware that the total school capacity exceeds the total students by more than 5%, the user should reduce the school capacity figures proportionately to remove the excess. (The reason for this is given in Section II(B), immediately after the mathematical equations.) The computer program will not automatically correct for excess school capacity.

SCHOOL CAPACITY AND ETHNIC COMPOSITION CARDS. The next set of cards, one for each school, describe capacities and ethnic percentage requirements. Each card is designed as follows.

Cols	1-6	XXXYYY (where XXX is the X coordinate and YYY is the Y coordinate of the school)
Col	7	blank
Cols	8-13	School name, e.g. PSbb83
Cols	14-16	blank
Cols	17-21	School capacity; e.g. b2625
Cols	22-34	bRACEbAbLL-BB where LL is the lower Race A percentage and BB is the upper percentage.
Cols	35-47	bRACEbBbLL-BB
Cols	48-60	bRACEbCbLL-BB

END-OF-CARD-FILE CARD. The last card has 999999 in cols 61-66.

3. Output. In Appendix E, pp. 1-3 give the assignments, for each tract, of students in various ethnic groups to schools. The program assigns sequence numbers to tract nodes according to X-Y order;

i.e. tract 000003 with coordinates (3, 15) is tract 1, tract 1176-1 with coordinates (5, 4) is tract 2, etc. The sequence number is a good index for finding a tract on the grid; the higher the sequence number, the farther to the right (of the Y-axis) is the Tract. The same sequence numbering is used for the schools. The program prints out the node descriptor along with the sequence number to avoid confusion.

For every assignment to a school from a tract, a recommended minimal-time bidirectional route is given, starting with the school node and ending with the tract node (from left to right). The intervening nodes, if any, are TB (bus line) nodes or U or W (subway line) nodes, whose coordinates are always given. As an example, take the last assignment at the bottom of p. 1. The recommended route is from PS413 at (8, 17) to U16 (subway line 16) at (10, 18). Subway line 16 is ridden to (8, 27), and a transfer is made to TB3 (bus line 3) at (10, 29). Bus line 3 is ridden to (12, 27), where the student disembarks, and his tract centroid is quite nearby, at (14, 29). To go <u>to</u> school, the student travels in reverse order.

Cost and Time information is printed out after every assignment. This information is summarized on p. 4 of Appendix E. Note that only 6.3 min. of transportation is required for the average student.

On p. 5 are the desired and achieved school ethnic compositions. In two cases (flagged by asterisks) there are slight departures from the input ethnic requirements. These reflect adjustments

made during the MPS/360 run; a solution would have been impossible without the adjustments.

B. Brooklyn, New York, elementary schools, 1960 data.

Brooklyn was chosen as a test case because it presents the difficult problem of overcoming extreme residential segregation. There are large areas of nonwhite population, such as Bedford-Stuyvesant, and large predominantly white areas, such as Bay Ridge.

In the Brooklyn case, Census Tracts were chosen as the geographic unit of student ethnic distribution. There are 783 Census Tracts in Brooklyn, each of which is typically between eight and fifteen blocks. The community-wide student racial percentages in 1960 for public grades K-6 were about 13.6% Race A (Puerto Rican), 24.2% Race B (Negro), and 62.2% Race C (Other), according to U. S. Census data. In view of these figures, it was decided to set the ethnic requirements at each of the 201 elementary (K-6) schools as follows: 7% to 35% Race A, 12% to 57% Race B, and 25% to 81% Race C. The total school capacity was 214,793 in the 201 elementary (K-6) schools, according to official New York City Board of Education figures; this exceeds the Census total of public K-6 students, which is 199,891.

Brooklyn has about 14 bidirectional subway lines, averaging about 35 mph; it also has about 70 bidirectional bus lines, averaging about 8 mph, making stops every two or three blocks. With a

walking distance limit* of 0.227 miles, and a daily one-way transportation time limit of 20 minutes, the MINTRAN run produced 17,013 minimal time routes from 783 Census Tracts to the 201 schools. In other words, for the average Census Tract there are about 22 schools within 20 minutes by available transportation, and there is at least one such school for every Census Tract.

The Brooklyn problem proved difficult to solve with MPS/360, mainly because of its size. Approximately 3,150 linear constraints must be handled. At this writing, the MPS/360 output is not ready, but is expected before January 1, 1968. An addendum will be filed to this report describing the MPS/360 results, the average transportation time per student, the total fare cost, the assignment of students to schools, and the recommended routes.

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*Refer to Section II(H) above for discussion of this limit.

VI. SUMMARY OF RELATED RESEARCH

There has been some interest in exploring related problem areas in the literature. A study was made by Fulkerson et. al.[1] in Los Angeles as part of a proposal to alleviate overcrowding and de facto segregation in elementary schools. This was to be done by means of free and voluntary bus transportation of children from overcrowded schools to schools in other parts of the city with unused classroom space. A "network flow" algorithm[2] was used for the assignment of students from overcrowded schools to schools with unused classrooms. Buses were used to accomplish the transportation. The assignment of students to buses was made manually. In conjunction with the San Francisco Unified School District, a study was undertaken to analyze alternatives for improving racial balance in school districts. In this study[3] attempts are made to establish measures of racial balance and examine pupil assignment plans. Another study done in Ithaca treats the school districting problem for a smaller community.[4]

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[1] D. R. Fulkerson et. al., "A Transportation Program for Filling Idle Classrooms in Los Angeles," RAND Report P-3405, July 1966.

[2] D. R. Fulkerson, "An Out-of-Kilter Method for Minimal Cost Flow Problems," Journal of Soc. Ind. Appl. Math, Vol. 9, No. 1, March 1961.

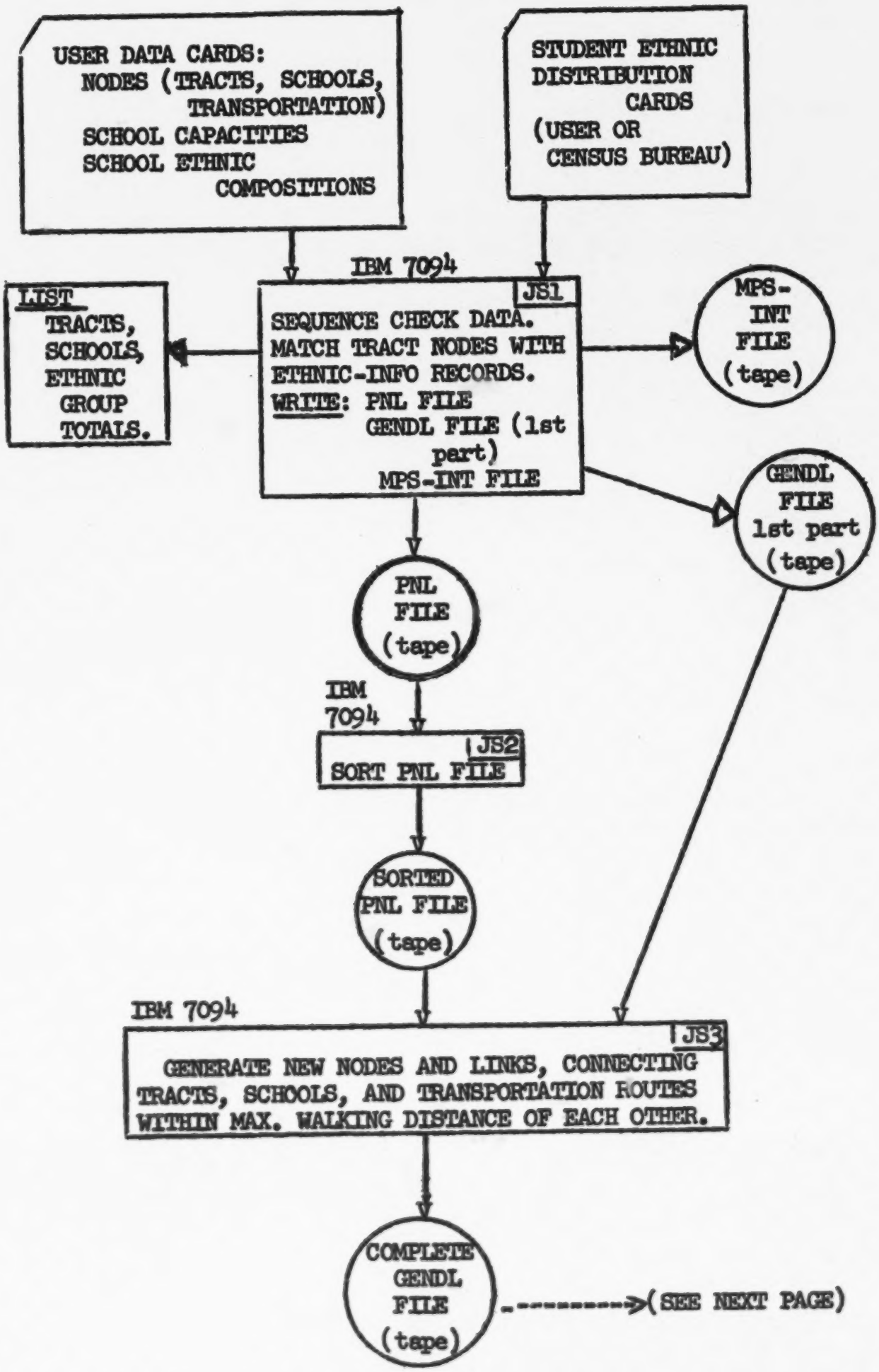
[3] B. Lefkowitz, D. A. D'Esopo, "Analysis of Alternative Methods for Improving Racial Balance in a School District," 31st ORSA Meeting, New York City, N.Y., May 1967.

[4] L. B. Heckman, "School Redistricting," M.S. Thesis, Graduate School of Cornell University, January 1968.

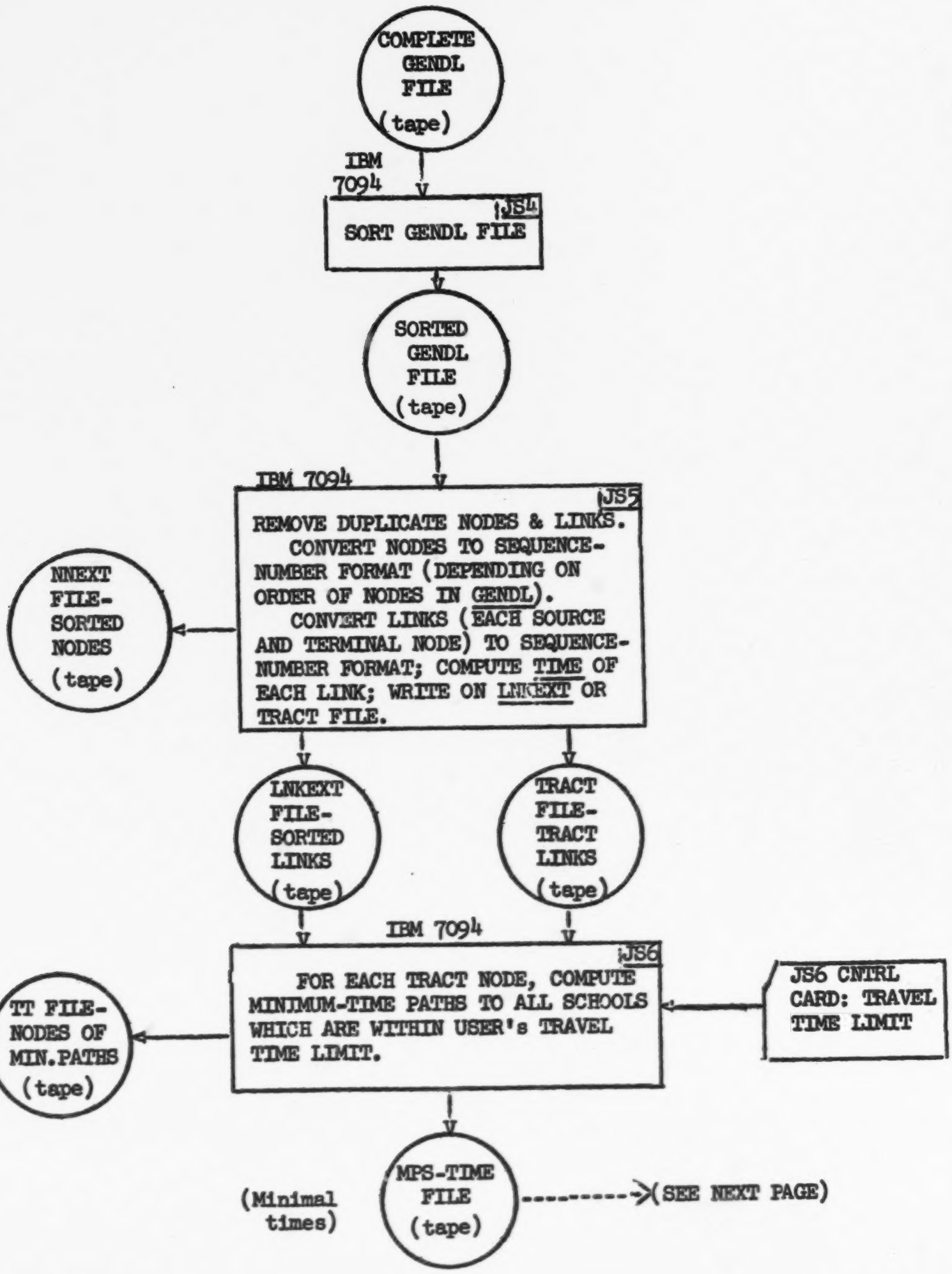
APPENDIX A

MINTRAN FLOW DIAGRAMS

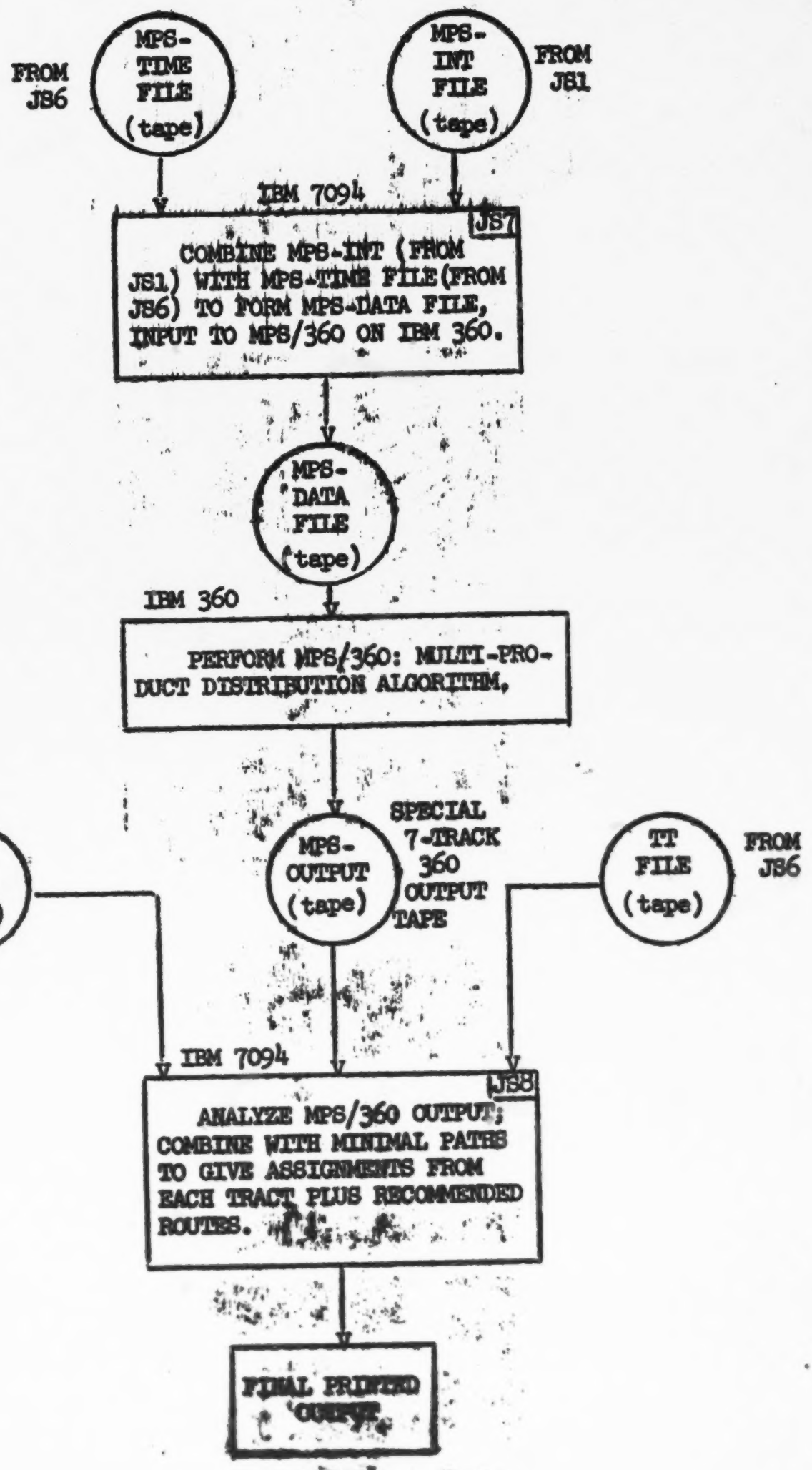
MINTRAN SYSTEM BLOCK DIAGRAM



MINTRAN SYSTEM BLOCK DIAGRAM


COMPLETE GENDL FILE (tape)
IBM 7094
JS4
SORT GENDL FILE
SORTED GENDL FILE (tape)
IBM 7094
JS5
REMOVE DUPLICATE NODES & LINKS. CONVERT NODES TO SEQUENCE-NUMBER FORMAT (DEPENDING ON ORDER OF NODES IN GENDL). CONVERT LINKS (EACH SOURCE AND TERMINAL NODE) TO SEQUENCE-NUMBER FORMAT; COMPUTE TIME OF EACH LINK; WRITE ON LNKEXT OR TRACT FILE.
NNEXT FILE-SORTED NODES (tape)
LNKEXT FILE-SORTED LINKS (tape)
TRACT FILE-TRACT LINKS (tape)
IBM 7094
JS6
FOR EACH TRACT NODE, COMPUTE MINIMUM-TIME PATHS TO ALL SCHOOLS WHICH ARE WITHIN USER's TRAVEL TIME LIMIT.
JS6 CNTRL CARD: TRAVEL TIME LIMIT
TT FILE-NODES OF MIN.PATHS (tape)
(Minimal times)
MPS-TIME FILE (tape)
(SEE NEXT PAGE)

MINTRAN SYSTEM BLOCK DIAGRAM


FROM J86
MPS-TIME FILE (tape)
MPS-INT FILE (tape)
FROM J81
IBM 7094
JS7
COMBINE MPS-INT (FROM JS1) WITH MPS-TIME FILE (FROM JS6) TO FORM MPS-DATA FILE, INPUT TO MPS/360 ON IBM 360.
MPS-DATA FILE (tape)
IBM 360
PERFORM MPS/360: MULTI-PRODUCT DISTRIBUTION ALGORITHM.
FROM JS5
NNEXT FILE (tape)
MPS-OUTPUT (tape)
SPECIAL 7-TRACK 360 OUTPUT TAPE
TT FILE (tape)
FROM JS6
IBM 7094
JS8
ANALYZE MPS/360 OUTPUT; COMBINE WITH MINIMAL PATHS TO GIVE ASSIGNMENTS FROM EACH TRACT PLUS RECOMMENDED ROUTES.
FINAL PRINTED OUTPUT

APPENDIX B

SAMPLE OF INPUT CARDS FOR HYPOTHETICAL COMMUNITY ("DUCKBURG")

INITIAL PARAMETER CARDS (DUCKBURG)

```
TOTAL INPUT NODES          WDIST   4 TRAVMAX 30.00SCONV 0.056R GRADE LIMITS 05-11
BUS SPEED    8.00 TRAIN SPEED 30.00 MAXNOD 7000 MAXLNK22000  DUCKBURG    CARD 2
```

SAMPLE ETHNIC INFO, ONE TRACT ONLY (DUCKBURG)

```
                                55    46    61    56    68    72    97        0003  1
                                                                              0003  2
                                                                              0003  3
                                                                              0003  4
                                                                              0003  5
                          335   309   171   194   160   105   214             0003  6
                                                                              0003  7
                                                                              0003  8
                                                                              0003  9
                                                                              0003 10
                    37    39    36    32    35    30    38                    0003 11
                                                                              0003 12
                                                                              0003 13
                                                                              0003 14
                                                                              0003 15
```

END-OF-ETHNIC INFO CARD (DUCKBURG)
(PRECEEDED BY 14 BLANK CARDS)

```
ZZZZZZ
```

NODE CARDS (DUCKBURG)

```
1 1  0003  3 15                                                          DUCKBURG 1960
1  1176-1  5  4                                                         DUCKBURG 1960
1    0091  7  7                                                         DUCKBURG 1960
1 1  0003  7 23                                                         DUCKBURG 1960
1    0008 13 15                                                         DUCKBURG 1960
1    0066 14 20                                                         DUCKBURG 1960
1    0032 19 20                                                         DUCKBURG 1960
1 1  0711 21 12                                                         DUCKBURG 1960
1 1  0711 22  6
1    0403 22 25                                                         DUCKBURG 1960
1  0820-1 26 26                                                         DUCKBURG 1960
1  0820-0 27 17                                                         DUCKBURG 1960
1  PS  83  4  9                                                         DUCKBURG 1960
1  PS 413  8 17                                                         DUCKBURG 1960
1  PS  19 14 27                                                         DUCKBURG 1960
1  PS   6 21  6                                                         DUCKBURG 1960
2  TB   3 10 292  TB   3 17 212  TB   3 22 212  TB   3 27 23          DUCKBURG 1960
2  TB   3 18 113  TB   3 18  12  TB  41 22 272  TB  41 16 17          DUCKBURG 1960
2  TB  41  1 102  TB  41  5  62  TB  41 16  73  TB  41 14  2          DUCKBURG 1960
2  TB  62  3 212  TB  62 10 192  TB  62  3 212  TB  62 10 19          DUCKBURG 1960
2  TB  62 14 203  TB  62 28 13                                         DUCKBURG 1960
2  U   16 17 322  U   16  8 272  U   16 10 182  W   16  6 17          DUCKBURG 1960
3  U   16  3  3                                                        DUCKBURG 1960
2  U    3 28 212  U    3 28  72  W    3 11 123  U    3  7  2          DUCKBURG 1960
9                                                                       END NODES
```

SCHOOL CAPACITY OPTION CARD (DUCKBURG)

EXCESS STUDENTS OPTION 0 DUCKBURG 1960

SCHOOL CAPACITY AND ETHNIC COMPOSITION CARDS (DUCKBURG)

```
 4  9 PS  83    2625 RACE A  7-28 RACE B 12-48 RACE C 30-81DUCKBURG 1960
 8 17 PS 413    3379 RACE A  7-28 RACE B 12-48 RACE C 30-81DUCKBURG 1960
14 27 PS  19    2653 RACE A  7-28 RACE B 12-48 RACE C 30-81DUCKBURG 1960
21  6 PS   6    3343 RACE A  7-28 RACE B 12-48 RACE C 30-81DUCKBURG 1960
```

END-OF-CARD-FILE CARD (DUCKBURG)

999999 END NODEFILE

APPENDIX C

MAP OF HYPOTHETICAL COMMUNITY ("DUCKBURG")

"DUCKBURG" COMMUNITY MAP

LEGEND

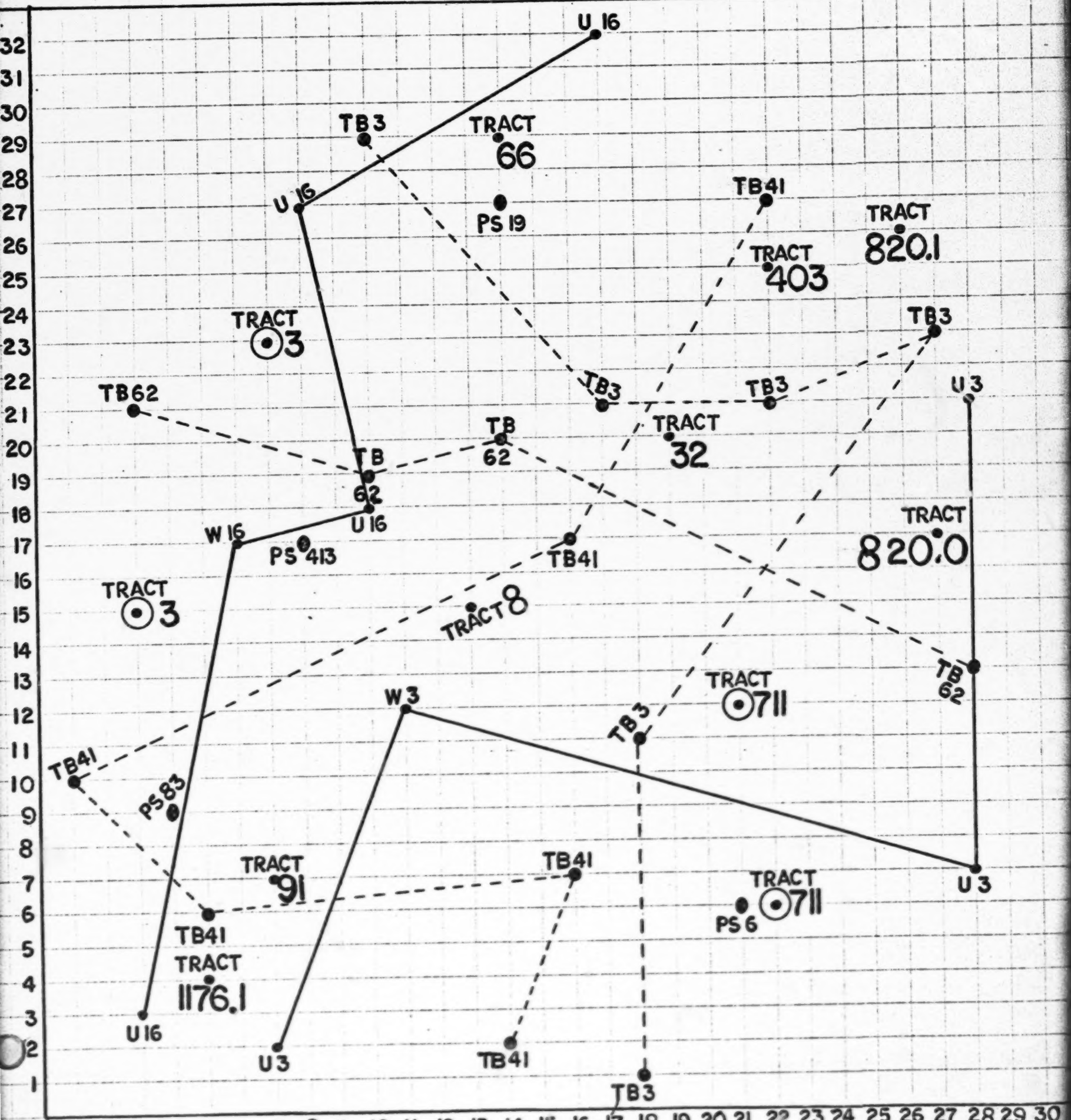
- ⊙ DENOTES SUBDIVIDED TRACT
- ---- BUS ROUTE (8 mph)
- ——— SUBWAY ROUTE (30 mph)
- PS SCHOOL
- TB BUS ROUTE NODE
- U or W SUBWAY ROUTE NODE

MAXIMUM WALKING DISTANCE 4 UNITS (one inch)

MAXIMUM TRAVEL TIME 20.00

ONE GRID UNIT = 0.0568 MILES

NOTE: Tract 820.0 is empty in this example.



APPENDIX D

ETHNIC DISTRIBUTION IN HYPOTHETICAL COMMUNITY

CENSUS FILE - DUCKBURG

SEQUENCE NUMBER	TRACT	ALL RACES	RACE A	RACE B	RACE C
1	0003	1143 (100%)	225 (19.6%)	795 (69.5%)	123 (10.8%)
2	1176.1	1128 (100%)	7 (.6%)	15 (1.3%)	1106 (98.0%)
3	0091	731 (100%)	116 (15.8%)	333 (45.5%)	282 (38.6%)
4	0003 Subd.	1143 (100%)	225 (19.6%)	794 (69.5%)	124 (10.8%)
5	0008	1050 (100%)	51 (4.8%)	991 (94.3%)	8 (.7%)
6	0066	1243 (100%)	665 (53.4%)	198 (15.9%)	380 (30.5%)
7	0032	531 (100%)	8 (1.5%)	27 (5.0%)	496 (93.4%)
8	0711	1751 (100%)	172 (6.9%)	131 (7.5%)	1497 (85.5%)
9	0711 Subd.	1751 (100%)	173 (6.9%)	132 (7.5%)	1497 (85.5%)
10	0403	1062 (100%)	17 (1.6%)	11 (1.0%)	1034 (97.4%)
11	0820.1	2364 (100%)	461 (19.5%)	3 (.01%)	1900 (80.9%)
	0820.0	EMPTY			
TOTALS		13907 (100%)*	2020 (14.5%)	3430 (24.7%)	8447 (60.7%)

*This total population exceeds the total school capacity by 1897 (15.8%)

Note: Subdivided tracts are tracts which cover large geographical areas, e.g. Tract 0003 and Tract 0711. The population in these tracts is halved, and one is designated "subd.".

APPENDIX E

OUTPUT FOR HYPOTHETICAL COMMUNITY ("DUCKBURG")

TRACT 1 (000003 3 15)-

ASSIGN TO SCHOOL 12 (PS 83 4 9)- RACE A 225, RACE B 794, RACE C 123 - TOTAL 1142.
RECOMMENDED ROUTE-
PS 83 4 9 - TB 41 3 8 - TB 41 1 10 - TB 41 5 12 - 000003 3 15 -
ROUND-TRIP DAILY COST $ 0.30 PER STUDENT OR $ 342.60 TOTAL, TIME 6.24 MIN PER STUDENT OR 118.77 STUDENT-HRS TOTAL.

TRACT 1 (000003 3 15)- TOTAL STUDENTS 1142, RACE A (PR) 225, RACE B (NEG) 794, RACE C (OTH) 123.

TRACT 2 (1176-1 5 4)-

ASSIGN TO SCHOOL 12 (PS 83 4 9)- RACE A 7, RACE B 15, RACE C 1106 - TOTAL 1128.
RECOMMENDED ROUTE-
PS 83 4 9 - TB 41 3 8 - TB 41 5 6 - 1176-1 5 4 -
ROUND-TRIP DAILY COST $ 0.30 PER STUDENT OR $ 338.40 TOTAL, TIME 2.44 MIN PER STUDENT OR 45.87 STUDENT-HRS TOTAL.

TRACT 2 (1176-1 5 4)- TOTAL STUDENTS 1128, RACE A (PR) 7, RACE B (NEG) 15, RACE C (OTH) 1106.

TRACT 3 (000091 7 7)-

ASSIGN TO SCHOOL 12 (PS 83 4 9)- RACE A 116, RACE B 333, RACE C 282 - TOTAL 731.
RECOMMENDED ROUTE-
PS 83 4 9 - 000091 7 7 -
ROUND-TRIP DAILY COST $ 0.00 PER STUDENT OR $ 0.00 TOTAL, TIME 0.02 MIN PER STUDENT OR 0.24 STUDENT-HRS TOTAL.

TRACT 3 (000091 7 7)- TOTAL STUDENTS 731, RACE A (PR) 116, RACE B (NEG) 333, RACE C (OTH) 282.

TRACT 4 (000003 7 23)-

ASSIGN TO SCHOOL 13 (PS 413 8 17)- RACE A 225, RACE B 795, RACE C 124 - TOTAL 1144.
RECOMMENDED ROUTE-
PS 413 8 17 - TB 62 9 19 - TB 62 6 20 - 000003 7 23 -
ROUND-TRIP DAILY COST $ 0.30 PER STUDENT OR $ 343.20 TOTAL, TIME 2.72 MIN PER STUDENT OR 51.86 STUDENT-HRS TOTAL.

TRACT 4 (000003 7 23)- TOTAL STUDENTS 1144, RACE A (PR) 225, RACE B (NEG) 795, RACE C (OTH) 124.

TRACT 5 (000008 13 15)-

ASSIGN TO SCHOOL 13 (PS 413 8 17)- RACE A 51, RACE B 991, RACE C 8 - TOTAL 1050.
RECOMMENDED ROUTE-
PS 413 8 17 - TB 41 9 14 - TB 41 11 15 - TB 41 13 15 - 000008 13 15 -
ROUND-TRIP DAILY COST $ 0.30 PER STUDENT OR $ 315.00 TOTAL, TIME 3.64 MIN PER STUDENT OR 63.70 STUDENT-HRS TOTAL.

TRACT 5 (000008 13 15)- TOTAL STUDENTS 1050, RACE A (PR) 51, RACE B (NEG) 991, RACE C (OTH) 8.

TRACT 6 (000066 14 29)-

ASSIGN TO SCHOOL 13 (PS 413 8 17)- RACE A 166, RACE B 0, RACE C 0 - TOTAL 166.
RECOMMENDED ROUTE-
PS 413 8 17 - U 16 10 18 - U 16 8 27 - TB 3 10 29 - TB 3 12 27 -
000066 14 29 -
ROUND-TRIP DAILY COST $ 0.30 PER STUDENT OR $ 49.80 TOTAL, TIME 34.52 MIN PER STUDENT OR 95.51 STUDENT-HRS TOTAL.

```
      ASSIGN TO SCHOOL   14 (PS  19    14    27)- RACE A    499, RACE B    198, RACE C    380 - TOTAL   1077.
      RECOMMENDED ROUTE-
      PS  19    14    27 - 000C66    14    29 -                    -                    -                    -
      ROUND-TRIP DAILY COST $ C.00 PER STUDENT OR $      0.00 TOTAL, TIME  0.02 MIN PER STUDENT OR      0.36 STUDENT-HRS TOTAL.

   TRACT    6 (000066    14    29)- TOTAL STUDENTS   1243, RACE A (PR)    665, RACE B (NEG)    198, RACE C (OTH)    380.

TRACT    7 (000032    19    20)-

      ASSIGN TO SCHOOL   13 (PS 413     8    17)- RACE A      8, RACE B     27, RACE C    496 - TOTAL    531.
      RECOMMENDED ROUTE-
      PS 413     8    17 - TB  62     9    19 - TB  62    10    19 - TB  62    14    20 - TB  62    18    18 -
      000032    19    20 -                    -                    -                    -                    -
      ROUND-TRIP DAILY COST $ 0.30 PER STUDENT OR $    159.30 TOTAL, TIME  8.20 MIN PER STUDENT OR     72.57 STUDENT-HRS TOTAL.

   TRACT    7 (000032    19    20)- TOTAL STUDENTS    531, RACE A (PR)      8, RACE B (NEG)     27, RACE C (OTH)    496.

TRACT    8 (000711    21    12)-

      ASSIGN TO SCHOOL   14 (PS  19    14    27)- RACE A      0, RACE B     68, RACE C      0 - TOTAL     68.
      RECOMMENDED ROUTE-
      PS  19    14    27 - TB   3    13    26 - TB   3    16    22 - TB   3    17    21 - TB   3    22    21 -
      TB   3    27    23 - TB   3    22    16 - TB   3    18    11 - 000711    21    12 -                    -
      ROUND-TRIP DAILY COST $ C.30 PER STUDENT OR $     20.40 TOTAL, TIME 27.02 MIN PER STUDENT OR     30.62 STUDENT-HRS TOTAL.

      ASSIGN TO SCHOOL   15 (PS   6    21     6)- RACE A    122, RACE B     63, RACE C   1497 - TOTAL   1682.
      RECOMMENDED ROUTE-
      PS   6    21     6 - TB   3    18     6 - TB   3    18     7 - TB   3    18    11 - 000711    21    12 -
      ROUND-TRIP DAILY COST $ 0.30 PER STUDENT OR $    504.60 TOTAL, TIME  4.28 MIN PER STUDENT OR    119.98 STUDENT-HRS TOTAL.

   TRACT    8 (000711    21    12)- TOTAL STUDENTS   1750, RACE A (PR)    122, RACE B (NEG)    131, RACE C (OTH)   1497.

TRACT    9 (000711    22     6)-

      ASSIGN TO SCHOOL   15 (PS   6    21     6)- RACE A    123, RACE B    132, RACE C   1497 - TOTAL   1752.
      RECOMMENDED ROUTE-
      PS   6    21     6 - 000711    22     6 -                    -                    -                    -
      ROUND-TRIP DAILY COST $ C.00 PER STUDENT OR $      0.00 TOTAL, TIME  0.02 MIN PER STUDENT OR      0.58 STUDENT-HRS TOTAL.

   TRACT    9 (000711    22     6)- TOTAL STUDENTS   1752, RACE A (PR)    123, RACE B (NEG)    132, RACE C (OTH)   1497.

TRACT   10 (000403    22    25)-

      ASSIGN TO SCHOOL   12 (PS  83     4     9)- RACE A      0, RACE B     11, RACE C     29 - TOTAL     40.
      RECOMMENDED ROUTE-
      PS  83     4     9 - TB  41     3     8 - TB  41     1    10 - TB  41    16    17 - TB  41    18    21 -
      TB  41    19    23 - TB  41    21    26 - 000403    22    25 -                    -                    -
      ROUND-TRIP DAILY COST $ C.30 PER STUDENT OR $     12.00 TOTAL, TIME 25.32 MIN PER STUDENT OR     16.88 STUDENT-HRS TOTAL.

      ASSIGN TO SCHOOL   13 (PS 413     8    17)- RACE A     17, RACE B      0, RACE C   1005 - TOTAL   1022.
      RECOMMENDED ROUTE-
      PS 413     8    17 - TB  41     9    14 - TB  41    11    15 - TB  41    13    15 - TB  41    16    17 -
      TB  41    18    21 - TB  41    19    23 - TB  41    21    26 - 000403    22    25 -                    -
      ROUND-TRIP DAILY COST $ C.30 PER STUDENT OR $    306.60 TOTAL, TIME 15.50 MIN PER STUDENT OR    264.02 STUDENT-HRS TOTAL.
```

TRACT 10 (0820-3 22 25)- TOTAL STUDENTS 1062, RACE A (PR) 17, RACE B (NEG) 11, RACE C (OTH) 1034.

TRACT 11 (0820-1 26 26)-

ASSIGN TO SCHOOL 14 (PS 19 14 27)- RACE A 24, RACE B 3, RACE C 1900 - TOTAL 1927.
RECOMMENDED ROUTE-
PS 19 14 27 - TB 3 13 26 - TB 3 16 22 - TB 3 17 21 - TB 3 22 21 -
TB 3 27 23 - 0820-1 26 26 - - - -
ROUND-TRIP DAILY COST $ 0.30 PER STUDENT OR $ 578.10 TOTAL, TIME 14.28 MIN PER STUDENT OR 458.63 STUDENT-HRS TOTAL.

ASSIGN TO SCHOOL 15 (PS 6 21 6)- RACE A 437, RACE B 0, RACE C 0 - TOTAL 437.
RECOMMENDED ROUTE-
PS 6 21 6 - TB 3 18 6 - TB 3 18 7 - TB 3 18 11 - TB 3 22 16 -
TB 3 27 23 - 0820-1 26 26 - - - -
ROUND-TRIP DAILY COST $ 0.30 PER STUDENT OR $ 131.10 TOTAL, TIME 17.02 MIN PER STUDENT OR 123.96 STUDENT-HRS TOTAL.

TRACT 11 (0820-1 26 26)- TOTAL STUDENTS 2364, RACE A (PR) 461, RACE B (NEG) 3, RACE C (OTH) 1900.

DAILY TOTALS- TOTAL STUDENTS 13897. OF WHICH 13337 MUST USE TRANSPORTATION (OTHER THAN WALKING). TRANSPORTATION COST $ 3101.10.

TOTAL TRANSPORTATION TIME 1463.55 STUDENT-HRS. OR 6.32 MIN AVERAGE.

SCHOOL ETHNIC COMPOSITIONS, DESIRED AND ACHIEVED

SCHOOL 12 (PS 83 4 91) CAPACITY 2625 ADJUSTED TO 3041
RACE A. DESIRED PERCENTAGE 7 TO 28, ACHIEVED 11
RACE B. DESIRED PERCENTAGE 12 TO 48, ACHIEVED 38
RACE C. DESIRED PERCENTAGE 30 TO 81, ACHIEVED 51

SCHOOL 13 (PS 413 8 17) CAPACITY 3379 ADJUSTED TO 3913
RACE A. DESIRED PERCENTAGE 7 TO 28, ACHIEVED 12
RACE B. DESIRED PERCENTAGE 12 TO 48, ACHIEVED 46
RACE C. DESIRED PERCENTAGE 30 TO 81, ACHIEVED 42

SCHOOL 14 (PS 19 14 27) CAPACITY 2653 ADJUSTED TO 3072
RACE A. DESIRED PERCENTAGE 7 TO 28, ACHIEVED 17
RACE B. DESIRED PERCENTAGE 12 TO 48, ACHIEVED 9 ******
RACE C. DESIRED PERCENTAGE 30 TO 81, ACHIEVED 74

SCHOOL 15 (PS 6 21 6) CAPACITY 3343 ADJUSTED TO 3871
RACE A. DESIRED PERCENTAGE 7 TO 28, ACHIEVED 18
RACE B. DESIRED PERCENTAGE 12 TO 48, ACHIEVED 5 ******
RACE C. DESIRED PERCENTAGE 30 TO 81, ACHIEVED 77

APPENDIX F

RUNNING INSTRUCTIONS FOR COMPUTER PROGRAMS

Throughout these instructions, reference should be made to Appendix A for flow diagrams. All tape mounting instructions refer to FORTRAN logical units. An IBM 7090 should be used for all "JS" programs. "Tape A", "Tape B", etc. refer to the user's own reels of tape. Tapes should be 2400 ft. and tested at 800 bpi.

JS1: All data cards (see Section V(A)(2)) in reader except for student ethnic distribution cards. The latter should be put on a card-image tape (Tape A) which is mounted on unit 13. Outputs are as follows.

UNIT 9 - Tape C ("GENDL file")
UNIT 10 - Tape B ("PNL file")
UNITS 12, 14, 16, 18 - up to 4 reels of "MPS-INT file", tapes D_1, D_2, D_3, D_4.

JS2: This is an IBSYS external sort.

INPUT — Tape B ("PNL file")

OUTPUT — Tape E ("SORTED PNL file")

JS3:

INPUTS — UNIT 11 - Tape E ("SORTED PNL file")
UNIT 9 - Tape C ("GENDL file")

OUTPUT — UNIT 10 - Tape F ("COMPLETE GENDL file")

JS4: This is an IBSYS external sort.

INPUT — Tape F ("COMPLETE GENDL file")

OUTPUT — Tape G ("SORTED GENDL file")

JS5:

INPUT — UNIT 11 - Tape G ("SORTED GENDL file")

OUTPUTS — UNIT 9 - Tape H ("NNEXT file")
UNIT 10 - Tape J ("LNKEST file")
UNIT 13 - Tape K ("TRACT file")

JS6:

INPUTS	UNIT 17 - Tape K ("TRACT file") UNIT 10 - Tape J ("LNKEXT file")
OUTPUTS	UNIT 11 - Tape L ("MPS-TIME file") UNIT 13 - Tape M ("TT file")

In addition to the tape inputs, there is one input card. It has the maximum daily one-way travel time, in minutes and hundredths of minutes, in cols 2-7. E.g., b20.00 would be a 20-minute maximum. This card can also be used to control checkpoints if a restart procedure is necessary.

JS7:

INPUTS	UNIT 9 - Tape L ("MPS-TIME file") UNIT 11 - Tape D_1 ("MPS-INT file, reel 1")
OUTPUTS	UNIT 12 - Tape N_1 ("MPS-DATA file, reel 1")

NOTE: for every reel D_1 of the MPS-INT file, a separate run of JS7 must be performed. The resulting output reel or reels comprise the "MPS-DATA file", which describes an L.P. problem in MPS/360 format.

MPS/360: See User's Manual, IBM Publications H20-0291-0 and H20-0291-1. This system requires an IBM System/360 to be run. The only functions used are CONVERT (which converts the MPS-DATA file to a Communications Format tape called PROBFILE) and PRIMAL. The output of PRIMAL, hopefully an optimal solution, must be put on a 7-track output tape. This MPS-OUTPUT file (Tape P) is then input to JS8 on the 7090.

JS8:

INPUTS	UNIT 9 - Tape M ("TT file") UNIT 10 - Tape H ("NNEXT file") UNIT 11 - Tape P ("MPS-OUTPUT file")
OUTPUT	Printer only.

In addition to the tape inputs to JS8, there is a small card input file which consists of the SCHOOL CAPACITY AND ETHNIC COMPOSITION cards followed by the END-OF-FILE card. These cards, described in Section V(A)(2) above, are used as input to JS1 and then re-used as input to JS8.

INDEX OF TAPES USED

Tape A - student ethnic input in card image form, one card per physical record of 84 characters; last 4 characters are blanks.

Tape B - PNL file (JS1 output)

Tape C - GENDL file (JS1 output)

Tapes D_1, D_2, D_3, D_4 - MPS-INT file, up to 4 reels (JS1 output)

Tape E - SORTED PNL file (JS2 output)

Tape F - COMPLETE GENDL file (JS3 output)

Tape G - SORTED GENDL file (JS4 output)

Tape H - NNEXT file (JS5 output)

Tape J - LNKEXT file (JS5 output)

Tape K - TRACT file (JS5 output)

Tape L - MPS-TIME file (JS6 output)

Tape M - TT file (JS6 output)

Tapes N_1, N_2, N_3, N_4 - MPS-DATA file, up to 4 reels (JS7 output)

Tape P - MPS-OUTPUT file (MPS/360 output)